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Review Article
Phytophagous Mites Associated to *Fragaria* spp., Advances in Pest Management in South America

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Abstract
Background and Objective: Phytophagous mites are considered key pests in strawberry worldwide however, there is a lack of information about the economic impact in South America. Understanding factors that affect the mite population establishment are crucial for design and success of a pest management program. A revision of the most valuable studies related to phytophagous mites associated to strawberry was made with special emphasis in South America. Besides, a structured questionnaire was used to assess pesticide knowledge, attitudes and practices among strawberry growers in some municipalities from the Province of Tungurahua. According to the review, most of the information about the impact and control of these mite species has been yielded in Europe and North America. In South America, the most information has been yielded in Brazil making this a fact that more studies are required from other South American countries such as Ecuador. According to the answers, farmers are able to recognize symptoms of mite feeding. They agreed that the only method known by them for pest control is using pesticides. Consequently, they neglect other strategies such as biological control, plant resistance or botanical pesticides. **Conclusion:** As strawberry exploitation was initiated in Tungurahua damage by phytophagous mites was evident and subsequent difficulties in the management of pest populations tended to increase due to mistakes in selection and application of acaricides. Despite this, there is no available information about pest mite management in Ecuador. Thus, this review aims to contribute to establish the basis for designing management sustainable programs available for Ecuadorian strawberry growers.

Key words: Pest mites, strawberry, management, Ecuador

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Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Strawberries belong to the genus *Fragaria* L. that comprises about 23 species distributed all over the North Temperate or Holarctic Zone[1,2] and South America[3]. *Fragaria* species exist as a natural polyploid series from diploid through decaploid[4]. Diploid *Fragaria* species are considered endemic to boreal Eurasia and North America, meanwhile, *Fragaria vesca* L. is native from the West of the Urals throughout Northern Europe and across the North American continent[4].

Strawberry is produced in many regions of the world at different times of the year to satisfy for cooler temperatures for plant development differing thus production practices in each climatic region[5].

The modern cultivated strawberry is grown in over 60 countries by 2012 had a worldwide production of over 4.5 million metric t and a total crop (fresh market and processing fruit) value of over $2.4 billion in the United States[6] being this the world's largest producer of strawberries, accounting for 29% of the total world's strawberry production. The next highest producer countries are Spain (11%), Turkey (7%), Egypt (5%) and Mexico (5%). Fresh market strawberry fruit accounted for 80% of total strawberry production in the US in 2012 meaning 30.1 billion pound valued at $2.2 billion.

In South America, the indigenous people of central and Southern Chile, cultivated strawberries. They developed a land race of the white Chilean strawberry (*F. chiloensis* subsp. *chiloensis f. chiloensis*), cultivated this fruit for thousands of years[4]. This variety was also grown in Ecuador in production systems ranging from fields where plants are relatively evenly spaced in all directions to systems very comparable to traditional matted row systems[7].

However, after 1950 high yielding of the new developed cultivars *F.×ananassa* began to displace much of the traditional *F. chiloensis* production[8,9]. Today, cultivars of *F.×ananassa* are found in almost all South American countries, flourishing in tropical, subtropical and Southeastern South America where the climate is strongly conditioned by fresh South Atlantic winds, with average temperatures ranging from 11°C in July to 24°C in January[10].

As in other crops, in strawberry, a number of factors, including physical injuries from insect pests and pathogens, influences the quality of fruits and, therefore, management strategies that will reduce strawberry injury from pests and pathogens are critical in enhancing the commercial product[11]. Investigations about pest and diseases attacking strawberries have shown that there are 5 main diseases such as powdery mildew (*Sphaerotheca macularis* f.sp. *fragariae*)[12], anthracnose (*Colletotrichum acutatum*, *C. fragariae* and *C. gloeosporioides*)[13], gray mould (*Botrytis cinerea*)[14], blight and root rot (*Gnomonia fragariae*)[15]. Besides a few major pests such as aphids[16,17], cutworms (*Agrotis ipsilon*, *Athetis mindara* and *Peridroma saucia*)[18] and red spider mites have been reported[11,19,20]. Regarding to phytophagous mites, *Tetranychus urticae* is a serious pest in most of the producing areas of strawberry[18,21,22], but also other spider mites species (*Tetranychus cinnabarinus*, *Eotetranychus lewisi*)[23,24] and a tarsonemid mite (*Phytonemus pallidus*)[25,26] could cause minor to severe damage depending on the geographic location, environmental conditions and others.

Facing the potential impact of the pests attacking strawberries worldwide, efforts to adequate knowledge on the strawberry pests, complex and beneficial insects and their biology are required in order to maximize fruit yield and quality, mainly in the Latin American region.

Phytophagous mites associated to strawberry culture worldwide with special emphasis in South America

***Tetranychus urticae* Koch (Acari: Tetranychidae):** Tetranychid mites constitute a considerable large group of obligate phytophagous mites in several crops worldwide of which three species, *Tetranychus cinnabarinus* Boisduval, *Tetranychus turkestani* (Ugarov and Nikolski) and *Tetranychus urticae* are detrimental to strawberries[24]. However, *T. urticae*, the Two Spotted Spider Mite (TSSM) is considered the most important pest mite in Brazil and other South American countries[27]. Additionally, the TSSM can inflict damage to some other different crops than strawberry, i.e., tomato, beans, soy, peach, fig, papaya and cassava[28].

The life cycle of tetranychid mites goes through five phases: Egg, larva, protonymph, deutonymph and adult[29] and they are commonly found on the abaxial surface of the leaves and they are easily detected because of the web when they also could lay eggs or directly on the leaf surface. The nymphs and adults of *T. urticae* feed on mature strawberry leaves by introducing their stylets in the mesophyll to ingest sap and chloroplasts leaving the leaf with reddish coloration[27,30,31] (Fig. 1).

All the stages of TSSM find safe site within strawberry leaf trichomes protecting themselves from predators[32]. At high infestation rates, TSSM can suppress flower and leaf development and thus reduce fruit yield[33,34] by up to 80%. Furthermore, Livinali *et al.*[21] demonstrated that *T. urticae* feeding might decrease fruit quality which is more severely affected when chemical control is used instead of biological control. In this regard, strawberry fruits from chemical treated

Fig. 1(a-b): Strawberry leaves showing, (a) Reddish coloration after *T. urticae* feeding as compared and (b) Uninfested leaves in province of Tungurahua, Ecuador

infested plants presented the higher levels of acidity and low levels of anthocyanin and phenolic compounds while those fruit from infested plants treated with biological control using predatory mites showed high levels of soluble solids and ascorbic acid, along with a high soluble solid content/titratable acidity ratio which indicated high-quality fruit.

***Phytonemus pallidus* (Banks) (Acari: Tarsonemidae):** The cyclamen mite, *Phytonemus pallidus* was first noticed in New York in 1898 and in Canada in 1908 and now it is widely distributed throughout North and South America, Hawaii, Europe and Asia[26,30]. This tarsonemid mite species is a pest of many ornamental flowers and shrubs such as cyclamen (*Cyclamen* spp.), African violet (*Saintpaulia ionantha*), geranium (*Geranium* spp.), fuchsia (*Fuchsia* spp.), larkspur (*Delphidium* sp.), petunia (*Petunia* spp.) and snapdragon (*Antirrhinum* spp.)[26]. In addition, the cyclamen mite can also feed on field-grown strawberries at high humidity conditions being considered as one of the major pest of this plant species[30]. More recently, *P. pallidus* has been reported on *Solanum quitoense* in Costa Rica[35] and grapevine in Brazil[36].

Cyclamen mites are usually found along the midvein of young unfolded leaves and under the calyx of just emerging flower buds. As summarized by Andrade-Bertolo *et al.*[36] the diagnostic characters are as follow: The adult females are about 250 µm long, ovoid, pale to yellowish brown and have two pairs of setae on dorsal propodosoma, the second pair much longer than setae on dorsal hysterosoma. Trichobothria are capitated partly or not covered by lateral margins of the prodorsal shield and apodemes 4 extend beyond the bases of setae 3b. The adult males are smaller than females (170 µm) and the leg IV has tibia and tarsus fused the propodosoma has four pairs of dorsal setae and the fourth is much shorter than the third pair and is lateral of the line forming by the first three setae.

In Peru, *P. pallidus* was recorded causing strawberry leaf twisting with a characteristic bronzing underside and consequently plants are stunted, while when mites feed on flowers, pistils became bronzed and twisted and petals slightly deformed and pinkish in color, causing damage to the future fruit if high mite populations are achieved[37]. In addition, the cyclamen mite feeding can provoke deformation in developing fruits or superficial cracks which can favor the entry of phytopathogens as *B. cinerea* and especially *Rhyzopus* sp.[37].

Other phytophagous mite species: Despite the strawberry is cultivated in various South American countries most of the reports about phytophagous mites associated to strawberry proceeds from North America and Europe. With the exception of some references from Brazil, information in Latin America is still lacking. In Brazil, Fadini *et al.*[19] reported that the red mite, *Oligonychus ilicis* (McGregor) has been found causing damage on strawberry growing in greenhouses and organic production systems however, this mite is not considered as a primary pest. According to these authors, when *O. ilicis* occurs in association to *T. urticae* apparently, they do not compete directly for feeding sites since, the former prefers to stay on the upper side surface while the latter preferred the underside. However, the coexistence of these two spider mite species could promote a chance for *O. ilicis* to induce defenses in strawberry plants enabling to reduce the TSSM fitness.

It is worth noticing other phytophagous mites such as *Tetranychus turkestani*, *Tetranychus cinnabarinus* and *Eotetranychus lewisi* (McGregor) which have been reported on strawberry plants in California, USA[38], coexisting with *T. urticae* populations. Although, *T. turkestani* may coexist with the TSSM the former prefers warmer climates. Due to morphological similarities between both *T. turkestani* and *E. lewisi* to TSSM, they can only be distinguished by the morphological characters of male genitalia and on the other hand, Lewis mite females are smaller and have small spots on the idiosoma[39]. The further investigations should be addressed to assess risks in South America.

In present years an increase in *E. lewisi* populations relative to *T. urticae* have been observed probably due to the biological and chemical control tools used to suppress *T. urticae* may have indirectly released *E. lewisi* from competition thereby allowing their populations to increase[23].

Strategies for management of pest mites

Chemical control: Mites population monitoring is a crucial step to make decisions about control however, by 2004 a threshold had not been established in all the producing areas[5] mainly in various countries in South America where chemical products are the most used strategy in strawberry and other crops.

The strawberry traditional production systems are frequently characterized by high efficacy in pest control and consequently high-quality fruits. Nevertheless, outbreaks of pest population and fruit with high residues of pesticides are common associated problems[40]. In this regard, selection of pesticides with low persistence and toxicity is tremendously imperative, however, this crucial step is hampered by a significantly low number of registered chemical products for strawberry pest control in South America[40].

The advances in developed miticides have been mainly related to the metabolic pathway in mites. Many of these have been used in strawberries with variable efficacy for the control of tetranychid and tarsonemid mites (Table 1), a very low proportion of them are currently traded and used in Ecuador.

Table 1: List of the most common miticides used in the strawberry crop

Chemical group	Mode of action	Commercial name
Bifenazate	Unkown	Acramite 50 WS floramite*
Acequinocyl	Mitochondrial complex III electron transport inhibitors energy metabolism (Good evidence that action at this protein complex is responsible for insecticidal effects)	Kanemite 15 SC*
Spiromesifen	Inhibitors of acetyl-CoA carboxylase lipid synthesis, growth regulation (Good evidence that action at this protein is responsible for insecticidal effects)	Oberon 2SC*
Etoxazole	Mite growth inhibitors growth regulation (Target protein responsible for biological activity is unknown, or uncharacterized)	Zeal
Fenpyroximate	Mitochondrial complex I electron transport inhibitors energy metabolism (Good evidence that action at this protein complex is responsible for insecticidal effects)	Fujimite 5EC
Hexythiazox	Mite growth inhibitors Growth regulation (Target protein responsible for biological activity is unknown, or uncharacterized)	Savey 50 DF nissorum*
Abamectin*	6 Glutamate-gated chloride channel (GluCl) allosteric modulators nerve and muscle action (Strong evidence that action at one or more of this class of protein is responsible for insecticidal effects)	Agri-mek 0.15EC Abacus Abba Epi-Mek Reaper Temprano Zoro* Vertimec* New mectin*
Fenbutatin-oxide*	Inhibitors of mitochondrial ATP synthase energy metabolism (Compounds affect the function of this protein, but it is not clear that this is what leads to biological activity)	Vendex 50WP
Bifenthrin	Sodium channel modulators nerve action (Strong evidence that action at this protein is responsible for insecticidal effects)	Brigade*
Fenpropathrin	Sodium channel modulators nerve action (Strong evidence that action at this protein is responsible for insecticidal effects)	Danitol*
Dicofol	Unkown	Kelthane
Propargite	Inhibitors of mitochondrial ATP synthase energy metabolism (Compounds affect the function of this protein, but it is not clear that this is what leads to biological activity)	Omite*
Botanical pesticides		
Narrow-range oil	Contact including smothering and barrier effects	Omni oil 6-E
Rosemary oil	Contact including smothering and barrier effects	Ecotrol, ecotec
Stylet oil	Contact including smothering and barrier effects	Organic JMS stylet oil JMS stylet oil
	Unknown	Biosan#
	Unknown	Bacthomite#
	Unknown	Cinnancar#

*Commercial products currently registered in Ecuador and # Not currently registered in Ecuador

Biological control: Most of the available information about biological control attempts is derived from studies in North America, Europe or Australia. Various phytoseiid mites species have been reported in association to *T. urticae* in strawberry plants [*Neoseiulus fallacis* (Garman) in Canada, *Neoseiulus womersleyi* (Schicha) in Australia, *Neoseiulus aurescens* (Athias-Henriot), *Neoseiulus zwoelferi* (Dosse), *Neoseiulus cucumeris* (Oudemans), *Typhlodromus pyri* (Scheuten), *Neoseiulus californicus* (McGregor) and *N. fallacis* (Switzerland) but also a gamasid mite [*Proprioseiopsis* California *jugortus* (Athias-Henriot)][41]. Although in less numerous than phytoseiids, anystid mites have been also found feeding an average of 39 *T. urticae* adult females/day in laboratory tests[42].

Biological control studies from South America have been carried out mainly in Brazil. The predatory mite *P. macropilis* was able to suppress the two-spotted spider mite populations on strawberry plants 28 days after being released (predator: prey ratio 1:100)[43]. Based on the results, authors suggested that *P. macropilis* mites should be released as soon as the presence of the two-spotted spider mite is detected in the field. Previously, Watanabe *et al.*[44] demonstrated that populations of *P. macropilis* and *Amblyseius idaeus* (currently named *Neoseiulus idaeus* Denmark and Muma) decreased to 1.5 or 0.8 individuals/leaf 6 days after being released on strawberry plants under greenhouse conditions, however, soon after number of mites began to increase achieving 5.7 or 3.2 mites/leaves. Results showed that both phytoseiid mite species reduced populations of *T. urticae* even more drastically than pesticides did.

Others Phytoseiidae species have been used in biological control of tetranychid mites on strawberry even when plants have been previously treated with pesticides. Thus, Sato *et al.*[45] observed that the population of *N. californicus* increased rapidly on strawberry plants when the mites were released 2 h after the application of propargite. Even when propargite was sprayed on the plants, 2 weeks after the first release, the population of *N. californicus* mites was not affected, indicating that this acaricide was innocuous to this predator. Moreover, the reduction of *T. urticae* numbers was much slower in the plot without acaricide application causing severe damage to the strawberry plants during the first 6 weeks (release plots), despite the release of more predaceous mites per plant. This indicated the relevance of the use of a selective acaricide in association with predaceous mites when *T. urticae* infestation levels are high.

According to Solomon *et al.*[41], there was little information on predation on *P. pallidus* by naturally-occurring predators however, some predatory mites such as *Galendromus occidentalis* (Nesbitt), *N. cucumeris*, *Neoseiulus reticulatus* (Oudemans) and *N. aurescens* have been reported feeding on tarsonemids. Nevertheless, these predatory mites built up too slowly when feeding on the tarsonemid mite making difficult to control the pest. At the moment of this review no further information was found in this regard.

Botanical acaricides: Botanicals insecticides can play an important role in pest management for organic production mostly in minor areas crops although, after generalization of the usage of synthetic chemical insecticides, they have been relegated to a trivial position[46]. As defined by El-Wakeil[47], botanical pesticides are naturally occurring chemicals extracted from plants and these natural pesticides are available as an alternative to synthetic chemical formulations.

The most used biopesticides include nicotine, rotenone, pyrethrum, plant essential oils and the synthetic derived such as pyrethroids, azadirachtin as well as potential new botanical products which show the most diverse mode of action including as competition with the neurotransmitter acetylcholine to disrupting the sodium and potassium ion exchange process[47]. However, the mode of action of some other botanical pesticides such as some essential oils remains not fully understood. Moreover, in most of the cases pest control is made by application of botanical extracts it is difficult to pinpoint the exact modes of action[47].

In several previous studies, botanical pesticides have proved to be efficient to control mites feeding on strawberry plants. In Brazil, Vicentini *et al.*[48] noted that both mortality and oviposition of *T. urticae* reared on strawberry leaves cv. Camarosa were affected by the extract of citronella grass (*Cymbopogon winterianus* Jowitt ex Bor) at different concentrations. Fifty percent of mortality was observed after 24 h after applications of ethanol extracts at concentrations 3-5% suggesting that effectiveness of the extract is observed within the first 24 h after application. Similarly, a deterrent oviposition effect was observed as evidenced by reducing in egg number in 76 and 86% at 24 and 120 h after application of extract.

Soto *et al.*[49] observed that applications of neem-based products at concentrations lower than LC_{95} controlled efficiently populations of *T. urticae* in strawberry plants. Besides, authors also found that applications of neem product showed to be more selective to the predatory mite, *P. macropilis* (1.2 fold more resistant than *T. urticae*) indicating that phytophagous mite control can be achieved using 0.06 mg ai/L with minimal effects on beneficial mites. In addition, Bernardi *et al.*[50] found that the mortality provoked in *T. urticae* by application of azadirachtin was similar to that by abamectin, however, more beneficial effects with azadirachtin were evident such as lower biological persistence and lower mortality level of the predatory mites (*N. californicus* and *P. macropilis*). Although, azadirachtin did reduce fecundity in phytoseiid mites by 50% egg viability was relatively high (>80%).

Although, azadirachtin has shown to be effective to control populations of the two-spotted spider mite in some cases, other species have proved higher effectiveness. Thus, *Tephrosia voggeli* (Hook) extract resulted to be more effective than neem oil against the two-spotted spider mite reared on strawberry plants cv. Oso Grande[51]. Probably deguelin (the major constituent) tephrosin and three other minor rotenoids occurring in methyl acetate fractions of *T. vogelii* are responsible for the mite mortality[51,52].

Based on the evidence from studies show that the use of ethanolic extracts of different plant species is a valuable tool for controlling *T. urticae* in strawberry crops[53].

Cultural strategies: In organic production cultural practices are important preventive strategies against pests and are the first phase in the management of arthropods and phytopathogens. Soil management including fertilization using organic amends as well as other cultural practices may be used to contribute to pest reduction in the field[54], but also curative options must be available to reduce insects in the field when just preventive strategies are not enough to keep mite populations under damaging levels. For example, strawberry planting material can be kept free of *P. pallidus* by immersing plant material in warm water (45°C) during 13-15 min and then in cold water or treat loosely stacked plants with saturated air[30] at 44.5°C for an hour. So far, plant resistance has not been used in cyclamen mite control. However, some evidence has shown that some varieties have higher resistance levels to the cyclamen mite.

Plant resistance in strawberry cultivars to mites: Although there is an increasing demand for certified food and free of pesticide residues the current conventional production models in agriculture are frequently based on high energy expenditure with pesticides and fertilizers. Consequently, constant review of conventional methods in agriculture is required in order to ensure sustainability over time and to minimize consequences for man and the environment[55]. Fadini *et al*.[40] proposed the term Integrated Production (IP) and defined it as a system that is located between conventional production and organic farming sometimes interpreted as an extension to integrated pest management which management practices are carried out in an integrated manner in order to improve the quality of food and reduce the use pesticides[56]. According to El Titi *et al*.[57] the integrated production is a system of agricultural exploiting that aims to produce food and other products through the use of natural resources and regulatory mechanisms to minimize the use of pollutants and to ensure sustainable agricultural production.

The main factor restricting strawberry production in many countries is yield losses from to 15 up to 92% or even whole plantations due to fungal diseases or pest attack[20,58]. However, due to the restrictions on pesticide use or even the forbiddances of them at all because of high ecological risk. Resistant varieties should become the main objective in strawberry disease management[20]. Plants have constitutive resistance which is continuously expressed independently of the presence or action of herbivores and on the other hand, induced resistance which is expressed against herbivores only after the injury and may act directly on the herbivores and natural enemies[59,60]. Previous studies have demonstrated that the strawberry has constitutive and induced defense mechanism to attack spider mite[60,61].

In contrast, some strawberry cultivars can show no presence or low level of induced resistance. Fadini *et al*.[40] found that neither the length of immature phases nor the number of eggs per female nor the survival of *T. urticae* reared on strawberry cv. IAC Campinas were altered by the pre-infestation suggesting that these results may be associated to lower level of induced resistance. Kielkiewicz[62], stated that the induced response in strawberry is characterized by an increase in quantitative and/or qualitative chemical or physical defenses thus, strawberry leaves previously attacked by *T. urticae* alter the concentration of secondary compounds, resulting in plant defense against herbivores, characterized in toxic or repellent effects[63]. In Brazil, Monteiro *et al*.[64] found differences in developmental time of immature stages of *T. urticae* on strawberry cultivars being shorter on cv' Diamante10' and longer on cv 'Camarosa', however the average cycle of the two-spotted spider mite was 21.8% lower on the latter cultivar as compared to 'Diamante10'. In addition, authors also observed high variability for the female development on 'Seascape' suggesting that this cultivar was not as suitable for rearing substrate as other strawberry cultivars. On the other hand, difficulties of larvae to get established on strawberry's leaf disk could be related to the presence of leaf defensive components which can have toxic or anti-digestive effects on the early immature stages of herbivores[65] and provoke high mite mortality due to the plant resistance by antibiosis[66]. Furthermore, according to Monteiro *et al*.[64], the observed delay in the development time high mortality and lower oviposition rate in *T. urticae* on 'Camarosa' could support the hypothesis that some antibiotic mechanisms may induce a higher adaptive cost and that the observed delay in the development time.

As in other plants, morphological features of leaves are thought to affect herbivores[67]. In general, the presence of trichomes has been shown to be a mechanism of defense against herbivores and thus leaves with a major number of non-glandular trichomes are considered more resistant to herbivores due to mechanical restrictions[68]. Luczynski *et al.*[69] found a negative relationship between the number and density of glandular and non-glandular trichomes in strawberry leaves and the oviposition and survival of the two-spotted spider mite. However, the density of non-glandular trichomes does not seem to be the key factor for the resistance of strawberry cultivars but rather, the presence of pre-formed glandular trichomes containing oxidative enzymes[70].

A study case: Point of view of the strawberry growers from province of Tungurahua, Ecuador in relation to control strategies for pest mites: In Ecuador, strawberry is mainly grown at Pichincha and Tungurahua provinces, in areas between 1,300 and 3,200 m above sea level with average temperatures ranging about 15°C. Chimborazo, Cotopaxi, Imbabura and Azuay contribute with a minor production. From 1990-1993, the national strawberry production rose to 2000 t. However, after this period a tendency to decrease the area harvested and consequently fruit production was observed[71] (Fig. 2). However, an 11% of average inter annual increase rate has been noted after 2005. Most of the national production (60%) is destined for domestic consumption, while the remaining is exported to USA, Spain and Netherlands[72].

In province of Tungurahua, the agriculture had been traditionally devoted to producing perennial fruit trees, mainly Andean species; however, in late 1900's the increase in international strawberry prices provoked a shift in production. Being the strawberry production currently concentrated in Canton Ambato, Tisaleo, Cevallos and Pelileo (Fig. 3). Factors other than prices, such as dollarization in Ecuadorian economy, lack of Government policies promoting agricultural production and even volcano eruptions in the late 90's contributed to promoting this shift in Tungurahuan agriculture.

Soon after strawberry exploitation was initiated in Tungurahua, damage by phytophagous mites also was evident and subsequent difficulties in the management of pest populations tended to increase due to mistakes in selection and application of acaricides which could provoke resistance to several molecules[72]. In spite of this context, the strawberry crop is increasing in Tungurahua however, a request on implementation of more sustainable strategies is on place. In this regard, a structured questionnaire[73] used to assess pesticide knowledge, attitudes and practices among strawberry growers (i.e., what strategies to control mite pests, use and frequency of pesticides) was applied in some municipalities from the Province of Tungurahua.

According to the answers, farmers are able to recognize symptoms of mite feeding (Fig. 4a) distinguishing it from damages caused by other pests or pathogens they describe it as yellowish or purple spots on leaves. Without any exceptions, the interviewed farmers agreed that the only method known by them for pest control is using pesticides such as vertimec, new mectin (abamectin), floramite (bifenazate), sulphur (wettable powder), amitraz (amitraz) and

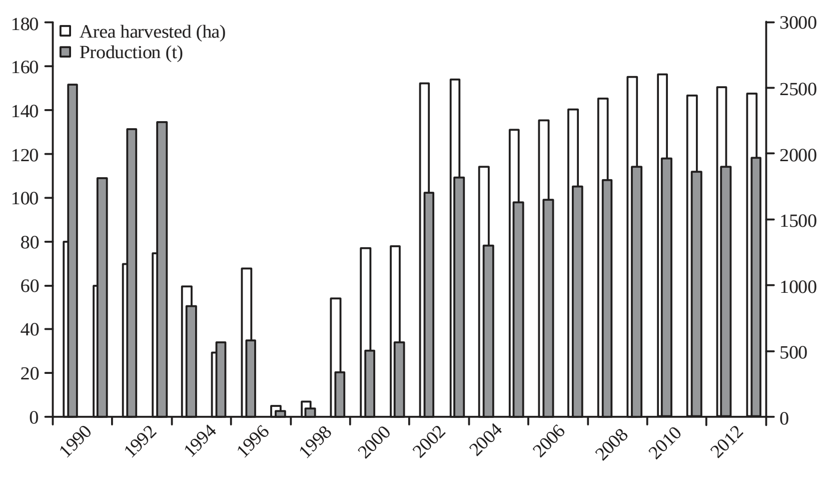

Fig. 2: Strawberry production and area harvested in Ecuador (1990-2013)

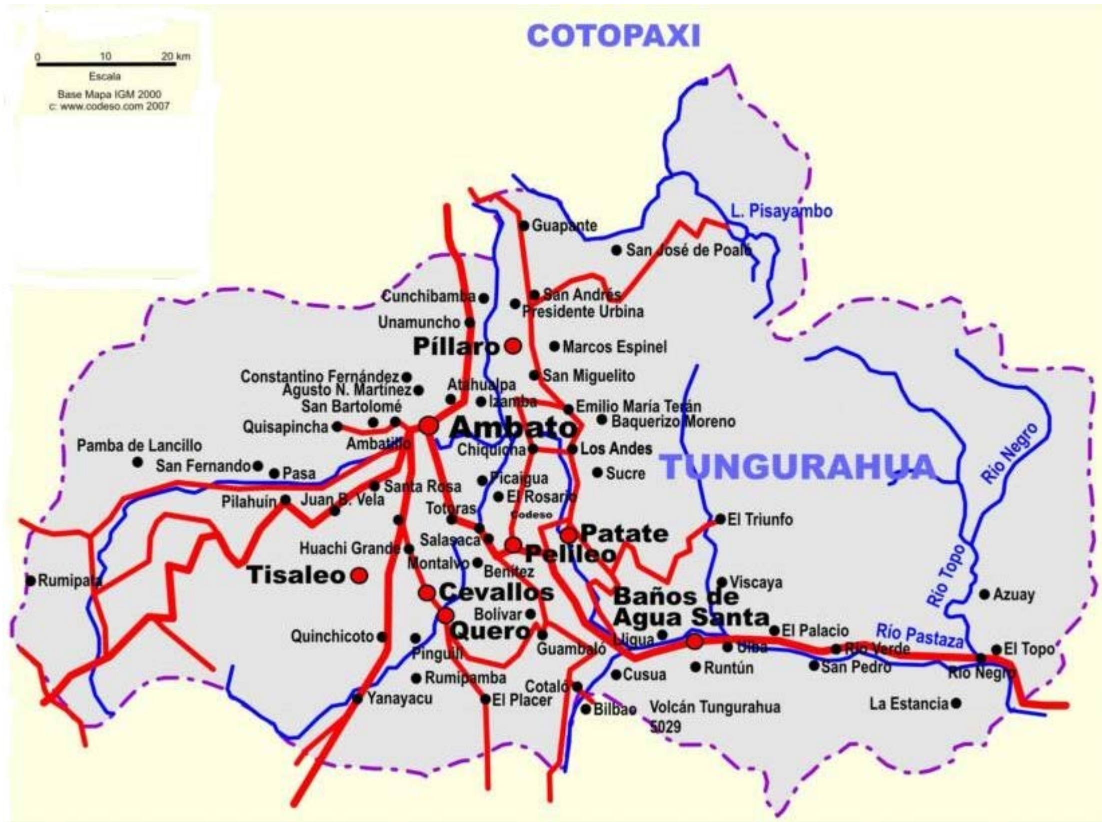

Fig. 3: Map of province of Tungurahua, Ecuador

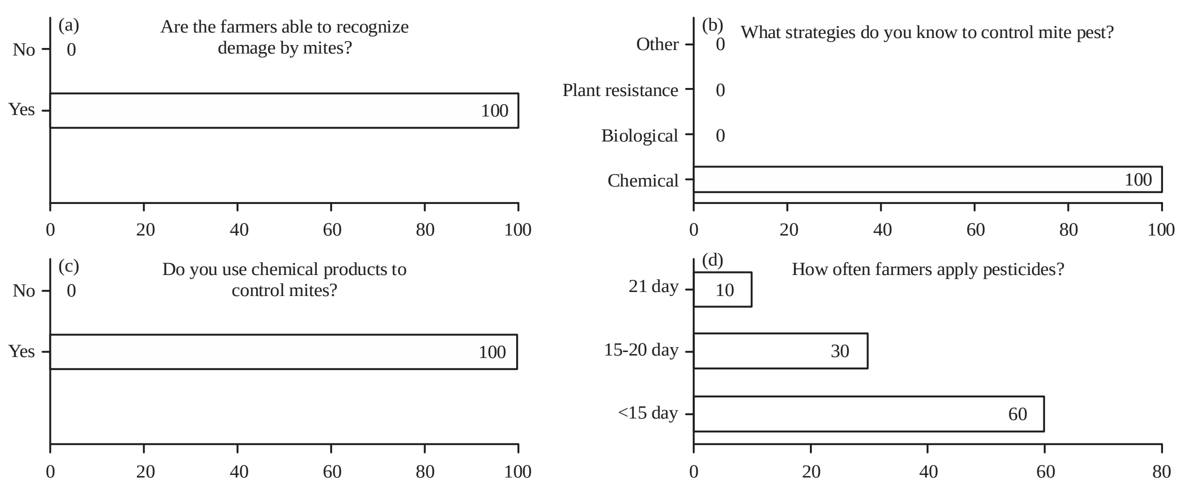

Fig. 4(a-d): Farmer's opinion about strategies for mite control in strawberry field crops in province of Tungurahua, Ecuador

commercial visits mediated (Fig. 4b-d). However, several of them said they did not remember a specific product. Besides chemical control being the only method of pest management applied in strawberry, frequency of application is other issue that deserve to be considered, since most of the farmers make pesticide applications at 15 days intervals (60% of the interviewed farmers) and only 10% repeat applications each 21 day (Fig. 4d). Although, information about the mode of action of pesticides was not included in the questionnaire, it seems to be a fact that growers do not know by any chance the way these products work and how they could affect the possibility for resistance if not well employed.

There is a worldwide tendency to use a large number of compounds with a different chemical structure and mode of action to control spider mites. However, *T. urticae* has showed ability to rapidly develop resistance to chemicals due to its high fecundity, inbreeding, arrhenotokous reproduction and very short life cycle resulting in many generations per year, especially in warmer conditions[74,75]. According to Van Leeuwen *et al.*[76], all these biological features have contributed to the fact that this species is currently considered as 'Most resistant', based on the total number of pesticides to which populations have become resistant, such as organophosphate, carbamates, pyrethroids, bifenazate[75,77,78] and also to the Mitochondrial Electron Transport Inhibitors (METI's) including quinazolines, pyrimidinamines, pyrazoles and pyridazinones[75].

By much, insecticides and acaricides are still considered as a viable (sometimes the only) strategy in pest control in field crops[76], therefore, more attention should be paid to resistance issue if more efficiency in pest management is desired. Thus, actions such as education program for farmers about the consciously use of pesticides should be included mainly in South American countries where the use of pesticides is tremendously increasing.

CONCLUSION

The impact of phytophagous mites on yield and quality of strawberry crops (mainly tetranychid and tarsonemid mites) has been shown in several countries worldwide, including in South America. Although, several strategies have proved different levels of efficacy for population management, chemical control is by far one of the most preferred tactics by farmers not only in Latin America but worldwide, even though its detrimental effects are well known but unfortunately not well understood so far. Some educational programs for farmers and even for the agricultural technician are required to promote the responsible and safe use of pesticides in strawberry production. In this regard, efforts from government and universities should be devoted to provide educational resources. This including pest identification, personal safety, safe storage and disposal of pesticides, pesticide drift and runoff prevention, threatened and endangered species protection, water quality protection and food safety, training programs and materials needed. All of these would help pesticide applicators to achieve certification and subsequently to maintain the knowledge to make use of pesticides safely and effectively, thus ensuring a healthy and sustainable agriculture.

It is clear that in Ecuador, especially in the province of Tungurahua, there is a lack of information about rationale pest mite management, such as biological control, biopesticides and/or plant resistance which if used in harmony with the chemical control could increase efficacy to diminish pest population and, consequently would decrease negative impact on environment.

SIGNIFICANCE STATEMENTS

Several tetranychid and tarsonemid mite species inflict severe damages to strawberries grown in field and in greenhouses, provoking important economic impact, thus they have been considered main pests in this crop. In South America, control of these mite pests has been based on chemical control. Unfortunately, most of the Ecuadorian farmers seem to be unfamiliarized with more ecologically sustainable strategies. Thus, in this review we intend to show how these alternative control methods, such as biological control, plant resistance and botanical pesticides would promote a safer way to manage pests for growers and environment.

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